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A clinical photogrammetric method to measure dental arch dimensions and mesio-distal tooth size

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SUMMARY The aim of this research was to evaluate the reliability and validity of measurements obtained from clinical standardized occlusal photographs compared with dental cast measurements. This study comprised a consecutive sample of 16 patients (eight males and eight females, aged 15–24 years) in the permanent dentition without agenesis and/or tooth loss. A paired *t*-test and intraclass correlation coefficient (ICC) were used to examine validity and reliability. Both statistics were applied for intra- and inter-methods error analysis, at $P < 0.05$.

Random error for the photogrammetric method (less than 0.48 mm) was similar to that for the dental cast measurements (less than 0.43 mm). ICC revealed excellent reliability for both methods ($P < 0.01$) and no significant difference for any variables, with the exception of upper inter-canine width obtained on the dental casts ($P = 0.0038$) and photogrammetry ($P = 0.01$). However, differences were less than 1 per cent of the mean inter-canine width. Inter-method analysis showed a significant correlation for all variables ($P < 0.001$), with good to excellent reliability ($r = 0.66$–0.93). A significant mean inter-method difference was consistently observed for the upper first molars (0.33 mm, $P < 0.01$). For the remaining teeth (left to right second premolars), the largest mean difference was approximately equal to the resolution of the human eye (0.2 mm or less). Minor differences (around 2 per cent of the mean) and an excellent ICC (0.75–0.93, $P < 0.01$) were observed for arch dimensions.

Except for the mesio-distal width of the upper first molars, the recently developed photogrammetric method showed accuracy, validity, and reliability acceptable for clinical and scientific purposes.

Introduction

The need for suitable storage and the risk of fracture are considered disadvantages when using dental casts as orthodontic records. Another limitation is the difficulty involved in accessing models. To avoid such disadvantages, dental casts have been reproduced in two dimensions via photocopies (Champagne, 1992) and photographs (Nollet *et al.*, 2004).

Recently, advances in digital technology have resulted in new three-dimensional methods. However, dental cast scanning seems to be the only option for eliminating model storage while providing reliable dental cast analysis (Santoro *et al.*, 2003; Quimby *et al.*, 2004; Paredes *et al.*, 2005, Mullen *et al.*, 2007; Oliveira *et al.*, 2007) and reducing analysis time (Callahan *et al.*, 2005; Oliveira *et al.*, 2007). Nonetheless, this method still requires a dental cast to be obtained, thereby increasing costs and causing some discomfort during impression taking (Dirksen *et al.*, 1999).

Few alternatives have been presented to reduce the need to obtain dental casts. In addition to its relatively high initial costs, laser intra-oral scanning requires further studies to confirm its accuracy. Due to improvements in the quality and low cost of images obtained with digital cameras, one possibility involves obtaining tooth size and dental arch measurements from intra-oral images. This method has rarely been investigated.

One study examined the reliability of intra-oral photographs (Gholston, 1984). Through occlusal photographs taken using an Orthoscan camera, it was observed that the measurements obtained from these images were reliable. However, there was a need for more detailed investigations to test the accuracy and reliability of this method. Furthermore, the equipment used by that author is no longer available.

The aims of this study are to present a new photogrammetric method to measure dental arch dimensions and tooth size and to examine the accuracy, reliability, and validity of the proposed methods in comparison with the measurements on conventional dental casts.

Subjects and methods

This research was approved by the Bioethics Committee, Dental School, UFPa., number 021/2008. Informed consent was obtained from all subjects.

Sample calculation

Sample size was determined using a paired *t*-test to identify a difference of 0.2 mm, the human eye resolution (Bille *et al.*, 2003), and standard deviation of differences of 0.25 mm, with 80 per cent power and a bilateral alpha level of 5 per cent. The sample size (n) calculated for these parameters was 14 individuals. The sample size (n) necessary to identify a predicted intraclass correlation coefficient (ICC) of 0.8 with a lower confidence limit of 0.6 (r), 80 per cent power, and alpha level of 5 per cent was 16 individuals (Walter *et al.*, 1998). Thus, a sample size of 16 individuals was defined as appropriate for examination. Both calculations were performed using BioEstat software (version 5.0, Mamirauá Maintainable Development. Institute, Belém, Pará, Brazil)

This study comprised a consecutive clinical sample of 16 patients, eight males and eight females, aged 15–24 years (mean 18.3 years), in the permanent dentition without agenesis and/or tooth loss. No other subject selection criteria were employed.

The occlusal photographs (n = 32) were obtained with a 10 megapixels digital camera (model Rebel XTi, Canon, Tokyo, Japan) with an 18–55 mm lens at the closest focusing distance (28 mm). Flat occlusal mirrors (model PM3R-4, Orthoply, Philadelphia, Pennsylvania, USA) were used to obtain the occlusal photographs. One standardized occlusal photograph of the upper and lower dental arches were obtained for each individual. The mirror was positioned in contact with the opposite dental arch to that being photographed, and the camera lens was as much as possible perpendicular to the flat mirror. Special attention was given to avoid tilting the mirror or the camera. In addition to prevent movement of the buccinator muscle and lips, an acrylic lip retractor (model 0118-LR, Orthoply) was used (Figure 1). An occlusal ruler was bonded on the acrylic retractor to allow dental arch images to be measured with the aid of digital software (Figure 2). Mesio-distal tooth

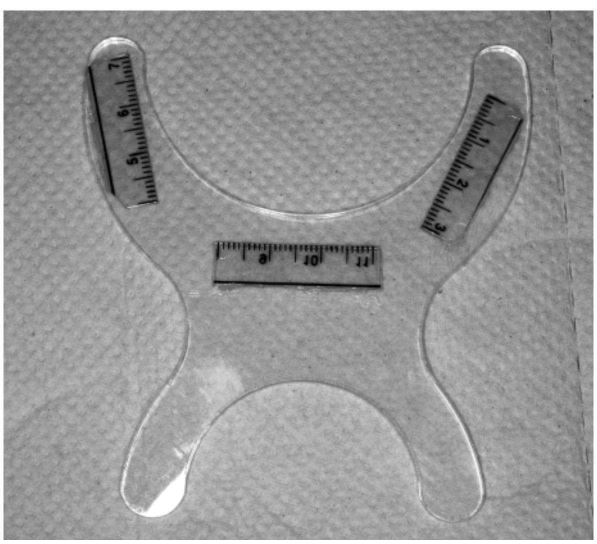

Figure 1 Standard occlusal photographs, in which an occlusal image of the dental arch is shown together with the occlusal millimeter ruler (parallel to the occlusal plane).

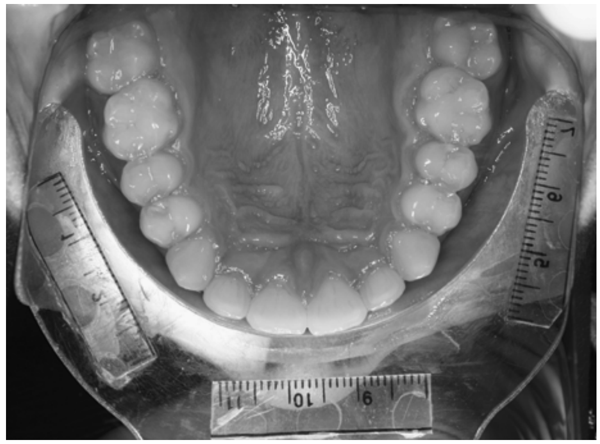

Figure 2 Tooth size (mesio-distal) and dental (inter-canine and inter-molar) arch measurements.

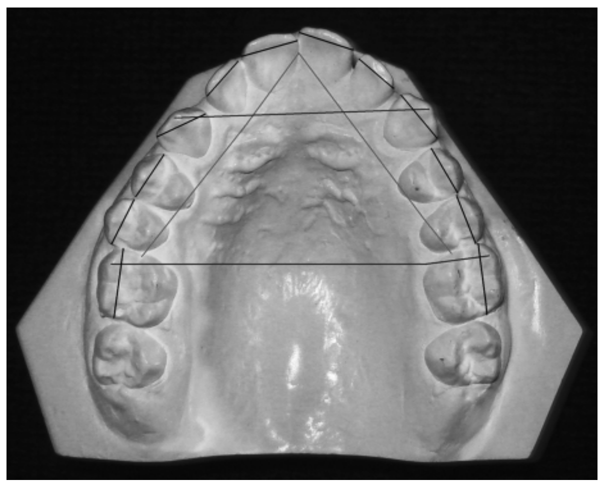

Figure 3 Occlusal millimeter ruler, made from an acrylic retractor for occlusal photographs. Straight segments of the ruler were bonded in the anterior and lateral portions of the retractor.

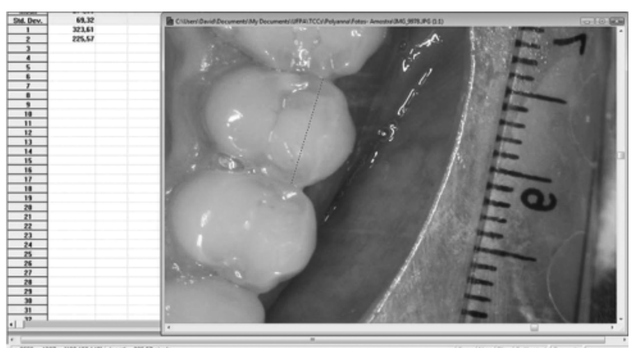

Figure 4 ImageTool interface after importing an occlusal photograph. Image magnification makes a more accurate reading possible. First, the number of pixels in 1 cm of the ruler (323.61) was obtained (line 1). The value obtained when reading the premolar width was 225.57 pixels. Cross-multiplication therefore determines the premolar width in millimeters (i.e., 225.57/323.61 = 0.69 cm, or 6.97 mm).

widths and dental arch dimensions (Figure 3) were measured twice ($T1$ and $T2$–1 month later) by a undergraduate dental student (Houston, 1983).

The obtained images were exported to ImageTool® software (University of Texas Health Science Center, San Antonio, Texas, USA), a free image processing and analysis program (http://ddsdx.uthscsa.edu/dig/download.html). Using this software, it was possible to obtain linear measurement in pixels (the smallest photographic element). Initially, the number of pixels in 1 cm of the occlusal ruler was read. A straight, 1 cm segment of the image measured in pixels was used as a parameter to convert the number of pixels in the real image to centimeters. Thus, all measurements obtained in pixels through the ImageTool software were converted to millimeters using cross-multiplication (Microsoft Excel; Redmond, Washington, USA; Figure 4).

The measurements from dental casts for each subject were obtained using a digital calliper (Fowler, model Ultra-Cal Mark III-Newton, Massachusetts, USA) with 0.01 mm sensitivity.

Thirty-two variables were examined. The photographic measurements were paired with values obtained from the models of each subject. Random error was examined by the formula proposed by Dahlberg (1940). Reliability was evaluated with the ICC (Fleiss, 1979) while validity was examined with a paired Student's t-test. Both statistics were applied for intra- and inter-methods, at $P < 0.05$, using the BioEstat statistical package.

Results

The random error observed for dental cast measurements ($T_1 \times T_2$) was approximately 0.1 mm (0.08–0.12) for dental width and ranged from 0.26 to 0.43 mm for dental arch dimensions. No significant difference was observed between T_1 and T_2; the sole exception was for upper canine

Table 1 Error study for dental cast method. Mean, standard deviation (SD), random error, mean difference, significance for the paired t-test, and intraclass correlation for the repeated measurements (T_1 and T_2).

Variable	T_1		T_2		Random error	$T_1 \times T_2$ (n = 16)				
						Difference $T_2 - T_1$		t-test	Intra-class correlation	
	Mean	SD	Mean	SD	Dahlberg	Absolute	%	Significance	r	Significance
UR1	8.77	0.39	8.73	0.35	0.11	0.04	0.5	0.39	0.91	***
UR2	6.81	0.33	6.81	0.29	0.13	0	0.0	0.88	0.86	***
UR3	7.74	0.39	7.72	0.36	0.13	0.02	0.3	0.66	0.88	***
UR4	7.26	0.47	7.22	0.5	0.1	0.04	0.6	0.34	0.95	***
UR5	6.92	0.47	6.91	0.5	0.08	0.01	0.1	0.8	0.98	***
UR6	10.33	0.6	10.39	0.58	0.12	−0.06	−0.6	0.16	0.96	***
UL1	8.85	0.27	8.79	0.34	0.12	0.06	0.7	0.22	0.82	***
UL2	6.88	0.34	6.82	0.33	0.07	0.06	0.9	1	0.96	***
UL3	7.74	0.4	7.7	0.37	0.09	0.04	0.5	0.18	0.94	***
UL4	7.2	0.39	7.15	0.43	0.09	0.05	0.7	0.22	0.93	***
UL5	6.91	0.49	6.9	0.46	0.11	0.01	0.1	0.7	0.95	***
UL6	10.3	0.61	10.31	0.62	0.09	−0.01	−0.1	0.78	0.99	***
LL1	5.34	0.19	5.38	0.23	0.09	−0.04	−0.7	0.18	0.82	***
LL2	6.01	0.31	6.06	0.33	0.1	−0.05	−0.8	0.16	0.9	***
LL3	6.6	0.42	6.64	0.47	0.1	−0.04	−0.6	0.16	0.95	***
LL4	7.24	0.33	7.26	0.32	0.08	−0.02	−0.3	0.41	0.95	***
LL5	7.18	0.32	7.26	0.3	0.1	−0.08	−1.1	0.08	0.93	***
LL6	10.88	0.44	10.93	0.44	0.12	−0.05	−0.5	0.13	0.94	***
LR1	5.38	0.22	5.32	0.25	0.12	0.06	1.1	0.26	0.57	*
LR2	6.03	0.36	6.03	0.38	0.09	0	0.0	0.92	0.95	***
LR3	6.67	0.41	6.66	0.44	0.1	0.01	0.1	0.73	0.96	***
LR4	7.15	0.29	7.2	0.35	0.07	−0.05	−0.7	0.06	0.95	***
LR5	7.28	0.45	7.24	0.46	0.1	0.04	0.5	0.27	0.96	***
LR6	10.97	0.51	10.92	0.5	0.1	0.05	0.5	0.12	0.96	***
Upper inter-molar width	52.24	3.29	52.25	3.24	0.32	−0.01	0.0	0.92	0.99	***
Upper inter-canine width	35.47	1.23	35.21	1.36	0.38	0.26	0.7	**	0.95	***
Upper right arch length	32.05	1.57	32.01	1.61	0.43	0.04	0.1	0.73	0.96	***
Upper left arch length	32.08	1.61	32.02	1.54	0.35	0.06	0.2	0.56	0.97	***
Lower inter-molar width	44.16	2.92	44.09	3.02	0.4	0.07	0.2	0.56	0.99	***
Lower inter-canine width	26.86	1.83	26.79	1.79	0.26	0.07	0.3	0.46	0.98	***
Lower right arch length	27.64	2.25	27.56	2.32	0.34	0.08	0.3	0.43	0.99	***
Lower left arch length	27.82	2.15	27.82	2.15	0.37	0	0.0	0.98	0.98	***

*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

Table 2 Error study for photogrammetric method. Mean, standard deviation (SD), random error, mean difference, significance for the paired *t*-test, and intraclass correlation for the repeated measurements (T_1 and T_2).

Variable	Photo-T_1		Photo-T_2		Random error	Photogrammetry $T_1 \times T_2$ ($n = 16$)				
						Difference $T_2 - T_1$		*t*-test	Intraclass correlation	
	Mean	SD	Mean	SD	Dahlberg	Absolute	%	Significance	*r*	Significance
UR1	8.68	0.4	8.58	0.43	0.26	0.1	1.2	0.25	0.70	***
UR2	6.71	0.34	6.74	0.36	0.14	−0.03	−0.4	0.57	0.89	***
UR3	7.54	0.47	7.59	0.5	0.18	−0.05	−0.7	0.38	0.87	***
UR4	7.27	0.43	7.26	0.45	0.22	0.01	0.1	0.92	0.84	***
UR5	6.81	0.44	6.81	0.56	0.22	0	0.0	0.92	0.88	***
UR6	10	0.56	10.06	0.61	0.2	−0.06	−0.6	0.34	0.91	***
UL1	8.68	0.34	8.61	0.45	0.18	0.07	0.8	0.25	0.87	***
UL2	6.7	0.31	6.66	0.38	0.19	0.04	0.6	0.55	0.70	***
UL3	7.53	0.47	7.49	0.39	0.18	0.04	0.5	0.54	0.85	***
UL4	7.08	0.48	7.11	0.45	0.12	−0.03	−0.4	0.42	0.95	***
UL5	6.84	0.52	6.86	0.49	0.14	−0.02	−0.3	0.69	0.93	***
UL6	9.97	0.59	10.07	0.61	0.2	−0.1	−1.0	0.10	0.92	***
LL1	5.26	0.22	5.32	0.29	0.13	−0.06	−1.1	0.18	0.80	***
LL2	5.9	0.33	5.94	0.33	0.13	−0.04	−0.7	0.39	0.87	***
LL3	6.47	0.39	6.44	0.48	0.13	0.03	0.5	0.54	0.93	***
LL4	7.14	0.32	7.19	0.38	0.18	−0.05	−0.7	0.37	0.81	***
LL5	7.13	0.38	7.15	0.33	0.16	−0.02	−0.3	0.63	0.84	***
LL6	10.69	0.56	10.75	0.52	0.14	−0.06	−0.6	0.21	0.95	***
LR1	5.36	0.37	5.32	0.27	0.15	0.04	0.7	0.52	0.75	***
LR2	5.82	0.37	5.8	0.44	0.12	0.02	0.3	0.65	0.93	***
LR3	6.48	0.46	6.44	0.42	0.15	0.04	0.6	0.53	0.88	***
LR4	7.16	0.37	7.19	0.43	0.15	−0.03	−0.4	0.48	0.88	***
LR5	7.24	0.56	7.13	0.52	0.23	0.11	1.5	0.13	0.86	***
LR6	10.85	0.49	10.82	0.54	0.14	0.03	0.3	0.47	0.94	***
Upper inter-molar width	52.01	3.2	51.99	3.33	0.39	0.02	0.0	0.87	0.99	***
Upper inter-canine width	35.28	1.12	35.01	1.3	0.37	0.27	0.8	*	0.93	***
Upper right arch length	31.64	1.7	31.67	1.66	0.31	−0.03	−0.1	0.79	0.98	***
Upper left arch length	31.38	1.8	31.31	1.63	0.41	0.07	0.2	0.60	0.96	***
Lower inter-molar width	43.66	3.17	43.66	3.16	0.48	0	0.0	0.99	0.98	***
Lower inter-canine width	26.7	1.81	26.86	1.88	0.38	−0.16	−0.6	0.15	0.97	***
Lower right arch length	26.97	2.08	26.8	2.24	0.41	0.17	0.6	0.14	0.98	***
Lower left arch length	27.25	2.18	27.18	2.04	0.29	0.07	0.3	0.44	0.99	***

*$P < 0.05$; ***$P < 0.001$.

width, which was 0.26 mm greater at T_1 ($P = 0.0038$). However, this difference represented less than 1 per cent of the absolute mean value at T_1. ICC analysis revealed excellent correlation (Fleiss, 1986), with *r* values ranging from 0.82 to 0.99. The only exception was observed for the lower right incisor ($r = 0.57$; Table 1).

Error analysis for the photogrammetric method was similar to that for the dental cast method. The random error between the T_1 and T_2 measurements from occlusal photographs ranged from 0.12 to 0.26 mm for tooth width and from 0.29 to 0.48 mm for dental arch measurements (Table 2). Similar to the findings observed for dental cast measurements, no statistically significant difference was found between the T_1 and T_2 measurements; the sole exception was for upper canine width, which was 0.27 mm greater at T_1 ($P = 0.01$). However, this difference was less than 1 per cent of the mean value at T_1. ICC for the photographic measurements at T_1 and T_2 (Table 2) was considered to be excellent (Fleiss, 1986) for most measurements ($r = 0.70$–0.99).

Photography versus dental cast

The ICC for the photographic and dental cast measurements (Table 3) showed significantly high reliability ($P < 0001$). Correlations for most examined measurements ($n = 30$) were classified as excellent ($r = 0.75$–0.93), whereas the remaining two (UR3 and UR6) showed a statistically significant correlation that was classified as "good" ($r = 0.66$; Table 3).

The mean differences between the methods revealed the absence of statistically significant differences for 25 of the

Table 3 Mean difference, significance for the paired *t*-test, and intra-class correlation coefficient for comparison measurements obtained from dental casts and photogrammetry at T_1.

Variable	Dental cast (T_1) × photogrammetry (T_1) (n = 16)				
	Difference DC − Photo		*t*-test	Intraclass correlation	
	Absolute	%	Significance	*r*	Significance
UR1	0.09	1.0	0.13	0.76	***
UR2	0.1	1.5	0.38	0.77	***
UR3	0.2	2.6	0.2	0.66	**
UR4	−0.01	−0.1	0.47	0.88	***
UR5	0.11	1.6	0.16	0.78	***
UR6	0.33	3.2	**	0.66	**
UL1	0.17	1.9	0.1	0.75	**
UL2	0.18	2.6	0.07	0.76	***
UL3	0.21	2.7	**	0.76	***
UL4	0.12	1.7	0.53	0.79	***
UL5	0.07	1.0	0.42	0.91	***
UL6	0.33	3.2	**	0.80	***
LL1	0.08	1.5	0.12	0.77	***
LL2	0.11	1.8	0.05	0.81	***
LL3	0.13	2.0	**	0.91	***
LL4	0.1	1.4	0.16	0.89	***
LL5	0.05	0.7	0.05	0.78	***
LL6	0.19	1.7	0.05	0.85	***
LR1	0.02	0.4	0.98	0.80	***
LR2	0.21	3.2	**	0.79	***
LR3	0.19	2.8	**	0.83	***
LR4	−0.01	−0.1	0.87	0.85	***
LR5	0.04	0.5	0.1	0.89	***
LR6	0.12	1.1	0.08	0.93	***
Upper inter-molar width	0.23	0.4	0.37	0.93	***
Upper inter-canine width	0.19	0.5	0.4	0.75	**
Upper right arch length	0.41	1.3	0.15	0.92	***
Upper left arch length	0.69	2.2	*	0.75	**
Lower inter-molar width	0.5	1.1	0.06	0.92	***
Lower inter-canine width	0.16	0.6	0.8	0.80	***
Lower right arch length	0.67	2.4	0.05	0.79	***
Lower left arch length	0.57	2.0	0.07	0.81	***

*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

32 variables examined. For the other seven measurements, a small but significant difference was found between the methods. A significant mean inter-method difference was observed for the upper first molars (0.33 mm, $P < 0.01$). For the remaining teeth (right to left second premolars), the size of the largest mean difference was approximately the same as the resolution of the human eye (0.21 mm for the LR2). With regard to arch dimensions, a significant difference was observed for upper left diagonal arch length ($P = 0.02$); this value was 0.69 mm larger on the dental casts. This mean difference corresponded to 2.2 per cent of the mean value at T_1.

For the seven variables showing a statistical significant difference, dental cast measurements were approximately 2–3.2 per cent larger compared with the photographic measurements.

Discussion

The results of this study demonstrated that a clinical occlusal photograph, taken in a standardized way with the aid of a lip retractor associated with a ruler, can serve as a reliable and valid instrument for measuring mesio-distal tooth width and dental arch dimensions. This method showed good to excellent reliability and only minor random errors. These data reinforce the use of this method as a reliable way of obtaining tooth size and dental arch dimensions. Only one previous study (Gholston, 1984) reported the accuracy of dental arch measurements obtained from occlusal photographs taken with specific equipment (Orthoscan). However, the photographic equipment used by Gholston (1984) is no longer available. Further, the author did not describe in detail the photographic technique or the method for reading the measurements. This hampers comparison of the results of the present study with previously published data.

Measurement readings at two different times (T_1 and T_2) performed by the same examiner for both methods revealed just one statistically significant difference. The average upper inter-canine width was approximate 1/4 mm larger at T_1 for both methods. Taking into account the limit of resolution of the human eye (i.e., 200 µm or 0.2 mm), this difference can be considered clinically insignificant and confirms the excellent reliability of the measurements obtained with both methods. A possible explanation for this bias can be related to the variability of the canine position in subjects with crowding.

The reliability and validity of the new method were examined by comparisons between measurements taken on the photographs and from models at T_1 (Table 3). This analysis showed that the measurements obtained from the photographs demonstrated a statistically significant high degree of correlation with dental cast measurements ($P < 0.01$).

Despite the high reliability, a paired *t*-test revealed some statistical differences in the validity of the two methods. Since the average difference was close to or below the limit of resolution of the human eye (Bille *et al.*, 2003), these minor differences must be considered clinically insignificant. The high sensitivity to identify these small differences could be related to the large sample size used in the paired *t*-test. However, one consistent or systematic error was observed when determining upper first permanent molar width. This tooth was 0.33 mm smaller when assessed using the photographic method. This difference may be related to difficulty in creating a standardized position for the mirror in this area or the angle formed between the lens and mirror when obtaining the occlusal photograph. Furthermore, the more posterior location of this tooth in the dental arch makes it difficult to obtain optimized images of the molar region. Further research should examine the influence of variations in the angle between the mirror and dental arch on the reading of the measurements of dental arch and tooth size.

The technological improvement of digital cameras provides images at low cost, with easy storage, conservation, and fast communicability. Despite the method's applicability, however, the findings indicate that dental casts should not be discarded from clinical orthodontic records; indeed, dental casts have many other clinical purposes. The photographic measurements obtained with the present method are a reliable alternative when there is difficulty in obtaining a dental cast (e.g., practical issues in the obtainment of dental arch impressions or research with isolated, indigenous, or aboriginal populations, patients using orthodontic appliance). Beside that, this photogrammetric method provides a fast and effective clinical control to determine the effects of orthodontic treatment on occlusal dimensions of the dental arch.

Conclusion

With the exception of the mesio-distal width of the upper first molar, the photogrammetric method is a reliable instrument for clinical and scientific application to measure dental arch dimensions and tooth size.

References

Bille J F, Buchler Costa J, Muller F 2003 Optical quality of the human eye: the quest for perfect vision. In: Bille F F, Harner C F H, Loesel F H (eds). Aberration-free refractive surgery. Springer, Heidelberg, pp. 25–46

Callahan C, Sadowsky P L, Ferreira A 2005 Diagnostic value of plaster models in contemporary orthodontics. Seminars in Orthodontics 11: 94–97

Champagne M 1992 Reliability of measurements from photocopies of study models. Journal of Clinical Orthodontics 26: 648–650

Dahlberg G 1940 Statistical methods for medical and biological students. George Allen and Unwin Ltd., London

Dirksen D, Diederichs S, Runte C, Bally G, Bollrnann F 1999 Three-dimensional acquisition and visualization of dental arch features from optically digitized models. Journal of Orofacial Orthopedics 60: 152–159

Fleiss J L 1979 Inter-examiner reliability in caries trials. Journal of Dental Research 58: 604–609

Fleiss J L 1986 The design and analysis of clinical experiments. John Wiley and Sons, New York

Gholston R L 1984 Reliability of an intraoral camera: utility for clinical dentistry and research. American Journal of Orthodontics 85: 89–93

Houston W J B 1983 The analysis of errors in orthodontic measurements. American Journal of Orthodontics 83: 382–390

Mullen S R, Martin C A, Ngan P, Gladwin M 2007 Accuracy of space analysis with emodels and plaster models. American Journal of Orthodontics and Dentofacial Orthopedics 132: 347–352

Nollet P J P M *et al.* 2004 Photographs of study casts: an alternative medium for rating dental arch relationships in unilateral cleft lip and palate. Cleft Palate-Craniofacial Journal 41: 646–650

Oliveira D D, Ruellas A C O, Drummond M E L, Pantuzo M C G, Lanna A M Q 2007 Confiabilidade do uso de modelos digitais tridimensionais como exame auxiliar ao diagnóstico ortodôntico: um estudo piloto. Revista Dental Press de Ortodontia e Ortopedia Facial 12: 84–93

Paredes V, Gandia J L, Cibrian R 2005 New, fast, and accurate procedure to calibrate a 2-dimensional digital measurement method. American Journal of Orthodontics and Dentofacial Orthopedics 127: 518–519

Quimby M L, Vig K W, Rashid R G, Firestone A R 2004 The accuracy and reliability of measurements made on computer-based digital models. Angle Orthodontist 74: 298–303

Santoro M, Galkin S, Teredesai M, Nicolay O F, Cangialosi T J 2003 Comparison of measurements made on digital and plaster models. American Journal of Orthodontics and Dentofacial Orthopedics 124: 101–105

Walter S D, Eliasziw M, Donner A 1998 Sample size and optimal designs for reliability studies. Statistics in Medicine 17: 101–110